THE UNIVERSITY OF ALBERTA

INFLUENCE OF K-Mg ANTAGONISM ON TOMATOES

by

©

Kanya-Lal Sahu

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

DIVISION OF HORTICULTURE

EDMONTON, ALBERTA

FALL, 1970

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Influence of K-Mg antagonism on tomatoes" submitted by Kanya Lal Kabu, in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Plant growth, fruit yield and uptake of the major cations was studied in tomato plants grown in perlite and fed with nutrient solutions containing two and six levels of potassium and magnesium respectively.

Under the higher potassium level (12 meq/liter) more magnesium was needed in the substrate to obtain comparable plant growth, fruit yield or number of fruits produced per plant than under the lower substrate potassium level (4 meq/liter). Mineral analyses indicated that the unavailability of magnesium is due to hindered uptake when both potassium and magnesium levels are high (12 meq/liter and 3 meq/liter, respectively). Under the high potassium and the low magnesium substrate levels the unavailability appears to occur within the plants. The antagonistic effect on potassium is operative under the lower concentrations of both potassium and magnesium. Potassium and magnesium act together in depressing the uptake of calcium.

Soil temperature and light intensity both appear to affect the magnesium uptake of tomato plants. High soil temperatures and high substrate potassium interact in reducing the uptake of magnesium. High light intensity appears to decrease magnesium uptake.

Under the high substrate potassium level the critical level of magnesium for optimum fruit production was significantly different from the level under the lower substrate potassium. No definite critical values, therefore, can be assigned to a crop, at least when ion interactions are involved.

ACKNOWLEDGEMENTS

I wish to express my gratitude to Dr. E. W. Toop for his guidance throughout the course of my research program and during the preparation of this manuscript.

I would like to express my thanks to Dr. Wm. T. Andrew for his valuable suggestions given to me from time to time. Appreciation is expressed to Dr. S. Pawluk for allowing the use of the Atomic Absorption Spectrophotometer. I acknowledge gratefully the help of Mr. P. D. Yee in the mineral analysis of the plant material and that of Messers H. Welling and R. Woudstra in the greenhouse experiments. My colleagues Messers E. B. Casement, P. Fedec, D. Shaw, D. Skoye and Miss E. Kruchowski are thanked for their constructive criticism and valuable suggestions.

The financial assistance from Alberta Agricultural Research Trust is gratefully acknowledged.

Sincere appreciation is extended to my father, Mr. G. R. Kabu for his financial assistance which enabled me to come to the University of Alberta from my home in Kashmir and to him and other relatives for caring for my family in my absence. I also appreciate the patience shown to me by my wife, Asha and children, Indira and Rajesh during the course of this work.

I would like to gratefully acknowledge the encouragement I received from my mother who, I regret to say, has recently departed from us while the latter portion of this work was being completed.

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INTRODUCTION

Magnesium deficiency has been reported on a wide range of crops under field conditions. In greenhouses it has been observed with considerable frequency on crops such as tomatoes, cucumbers and chrysanthemums. At Medicine Hat, Alberta tomato plants showing characteristic symptoms of magnesium deficiency were observed in the greenhouses.

It is natural to expect magnesium deficiency to occur on soils low in exchangeable magnesium, but, it is not infrequent to observe it even when the soil magnesium is considered adequate. This latter situation is encountered more often under greenhouse conditions than under field conditions and is believed to be induced by the relatively high levels of potassium usually maintained in greenhouse soils. Many references have been made to the aggravation of magnesium deficiency by potash fertilizing especially in recent years (3, 18, 43, 44).

Suprisingly, not much attention seems to have been paid to the extent to which potassium-induced magnesium deficiency can affect the growth, yield and mineral composition of susceptible crops. The object of this study was to investigate this in regard to greenhouse tomatoes and to relate this information to the established levels of magnesium in the indicator leaves believed to be adequate for optimal growth and yield.

The literature was found to provide very little information on the possible influence of soil temperature and light intensity on the magnesium deficiency induced by potassium fertilization.

That soil temperature would have a possible role in aggravating the problem was suggested by the fact that magnesium deficiency occurs more commonly on warm crops than on cool crops. Results of Winsor et al. (46) who obtained a significant yield response with magnesium applications on magnesium-deficient tomato plants in only one out of four years and that the one year coincided with a particularly sunny season, suggested a possible role of light intensity. These facts led to the inclusion of this aspect in these investigations.

It is claimed that magnesium deficiency can be readily corrected by occasional foliar spray applications of a magnesium salt. However, in view of the time and labour required such spray treatments are not popular with growers. It was thought worthwhile to include in the investigations an experiment to determine the stage or the stages of growth when the correction of magnesium deficiency could be postponed without any appreciable loss in tomato fruit yield.

REVIEW OF LITERATURE

A. MAGNESIUM DEFICIENCY

1. Introduction

Magnesium has been known to be essential for plant growth for a long time. Experiments conducted as early as 1849 and 1851 by Salm-Horstmar (in McMurtrey, 30) indicated that magnesia is one of the necessary ash constituents and in its absence plants are weak-stemmed with only the first three leaves having normal green color. The field deficiencies of this element, however, were not recognised until 1923 when Garner, McMurtrey, Bacon and Moss reported such deficiency symptoms (in Stewart, 36). They established that the condition known as sand drown in tobacco is caused by a deficiency of magnesium. Since that time there have been numerous reports of magnesium deficiency on a vast variety of crops from many parts of the world. Jacob (22) has reviewed a considerable volume of literature regarding the occurrence of magnesium deficiency on various crops.

2. Deficiency symptoms

The visual symptoms of magnesium deficiency have been described and illustrated by Embleton (11), Jacob (22), Sprague (34) and many others. As a general rule the most common symptom of magnesium deficiency in green plants is extensive intervenal chlorosis of leaves. It is first apparent on the basal leaves and as the deficiency becomes more acute the yellowing progresses towards the younger leaves. Chlorosis is often followed by the appearance of

anthocyanin pigments and following this necrotic spotting may occur. Occasionally the leaves curl upwards resulting in a puckered appearance (26). In severe cases the leaves fall off or die prematurely but remain attached to the plant as in oil palm (11). Mulder (31) observed that apple trees, variety Cox's Orange Pippin, with many fruits, had less leaf cast than those with only a few fruits. He explains that fruits act as a water reservoir for the leaves. The leaves suffering from a magnesium deficiency show an increased transpiration rate and cannot withstand a hot dry day without getting necrotic spots and falling.

The literature does not provide much reference to the symptoms as they occur on fruits. According to Woodbridge (47) apple fruits do not show any visual symptoms except for being small in size. However, under acute deficiency of magnesium the fruits may fail to ripen normally on the trees, are small, poorly colored and lacking in flavor (11).

The roots of magnesium deficient plants of tobacco are long, little branched and slimy in appearance. In the tomato plants as well, magnesium deficiency results in long roots with few branches (11). Reduction in the number of roots has also been observed by Laurie and Wagner (26) in geraniums.

Laurie and Wagner (26) have observed the magnesium deficiency in primroses to result in flowers which are poor in size, color and quality.

Seedless varieties of citrus are less susceptible to magnesium deficiency than those varieties which have seeds (11). Camp explains this on the basis that the seedless varieties produce

a more vigours root system with more ability to collect magnesium (5).

Varietal differences in the susceptibility to magnesium deficiency has also been observed by Woodbridge (47). The Jubliee and Newton apple cvs are more prone to show symptoms than the McIntosh, Jonathan and Rome Beauty. The Delicious and Winesap cvs seldom show leaf blotch, the characteristic symptom of magnesium deficiency in apples.

3. Occurrence of magnesium deficiency

i. Inherent magnesium deficiency

Magnesium deficiency is generally encountered on coarse textured soils of humid regions (11, 37). These soils normally contain inadequate amounts of exchangeable magnesium which are easily leached under heavy rainfall (33). On such soils the deficiency is usually less pronounced in years of low precipitation.

Besides the permeability of soil, the soil reaction is an important factor determining the extent of magnesium leaching. Because magnesium goes into solutions to a greater degree in acid soils than under neutral or alkaline conditions it is more strongly leached out under acid condition (11). Nevertheless magnesium deficiency has been reported on alkaline soils by Heymann-Horschberg is Isreal (11). Woodbridge (47) reported deficiences in apple orachards of British Columbia on soils ranging in pH from 4.9 to 8.2.

ii. Induced magnesium deficiency

Apart from inherent deficiences the supply of magnesium

to the crop can be seriously affected by the application of other nutrients. In the plant tissue the concentration of the nutrient ions does not change in a singular or an isolated manner. A change in the concentration of one ion is invariably accompanied by secondary changes in the tissue content of other dissimilar ions even when their supply remains unchanged (45). Ion interaction, as it is commonly known, has been defined by Emmert (13) as the enhancing or the depressing influence of one ion in a tissue on the accumulation of other ions of dissimilar species in that tissue. The interaction of ions involving the depressing influence of one ion on the other is often referred to as 'ion antagonism' and Jacob (22) defines it as the frequently observed phenomenon whereby the uptake of an ion by the plant is inhibited due to the increased supply of other ions. This may be a result of the soil processes or the influence of the plant itself. The deficiency of a nutrient in a plant resulting from ion antagonism is usually referred to as 'induced deficiency'.

Cain (4) observed that one ion has little, if any, direct effect on the total absorption of another ion by a tree although the percentage composition of one ion may be decreased by the application of another if its rate of absorption does not keep pace with the rate of growth stimulated by the added ion. Emmert (12) distinguishes true inter-ion influences from other sundry phenomena not involving inter-ion forces but which nevertheless produce statistically significant interaction. Apparent ion-interaction can result from the dynamic influences of an added element like nitrogen on plant growth; the increased tissue volume resulting in a dilution of other elements in the tissue.

Welte and Werner (44) differentiate between the physico-chemical cation interaction and the specifically physiological antagonism. The physico-chemical Donnan laws govern the exchange adsorption of magnesium and other cations at the sorption complex of the soil and the sorption sites in the 'free space' of the plant root. In the magnesium deficient soils of high sorption capacity having the magnesium ions intensely bound, an application of potassium can improve the magnesium supply to the plant by releasing some of the bound magnesium ions. However, in coarse soils low in sorption capacity this displacing action of potassium actually reduces the magnesium supply to the plant by promoting the leaching of this element. The physiological antagonism is based on the ion competition for the sorption sites of the organic structures functioning as the 'carrier' molecules in the process of active cation uptake.

According to Jacob (22) the difference in the speed of diffusion can cause certain ions with high mobilities to enter plant cells perferentially thereby disturbing the equilibrium. The ions entering more quickly make the entrace of comparatively slowly moving ions more difficult.

In the plant the magnesium ion is exposed to a whole series of antagonism with calcium, hydrogen, ammonium, manganese and, most important of all, the potassium ion.

B. POTASSIUM-INDUCED MAGNESIUM DEFICIENCY

The statement by Boynton and Burrell (2) "------------- it is interesting that the published experimental work on magnesium deficiency and its control in apple orchards of England, New Zealand,

Canada and Massachusetts has followed a period of three or more years during which potassium fertilization has become a rather common practice in these areas ------" indicates the importance of potassium fertilization to the occurrence of magnesium deficiency. The symptoms of magnesium deficiency in plants have been observed as a result of heavy potash fertilizing, despite an apparently adequate concentration of this element in an easily available form in the soil (3, 40). The references to the aggravation of magnesium deficiency by potash fertilizing occupy quite a sizeable space in the literature.

It was in the late 30's of the present century that the accentuating effect of potassium on magnesium deficiency was first pointed out by investigators such as Kidson, Southwick and Wallace. Drosdoff and Kenworthy (10) suggest that the severity of magnesium deficiency in some Florida orchards could have resulted from previous applications of approximately five tons of tung hulls per acre which would have contained upto 3.5 % K_2O. They further found lesser response to epsom salt when this was applied with potassium fertilizers. Prince et al. (32) found that the most important single factor influencing the magnesium uptake of plants is the quantity of potassium that is available for their use. When potassium is in abundance the magnesium content of the plants is low.

Walsh and O'Donohoe (40) recommended that the potassium/ magnesium ratio of both the plant and the soil merit attention when attempting to account for the development of magnesium deficiency. The wider the ratio in each case the greater the tendency towards its development. Van Der Boon et al. (38) observed that magnesium

deficiency was most closely related to the K/Mg ratio both in soil and foliage. They claim that no magnesium deficiency symptoms will occur in apples when the K_2O/MgO ratio in soil is less than 0.6 or less than 6 in the leaf. According to Chapman (7), Bingham et al. found that potassium-induced magnesium deficiency occurred on orchard soils of Florida where the ratio of exchangeable potassium to magnesium exceeds 0.5. Welte and Werner (44) have reported that potassium-induced magnesium deficiency symptoms can occur in arable crops if the K/Mg ratio exceeds about 15-20, provided that the absolute magnesium level of the plant is relatively low. McColloch et al. (29) report that an exchangeable-K/Mg value greater than 0.4 to 0.5 is suggestive of magnesium deficiency. Branson et al. (3) claim that soil K/Mg ratios greater than 0.5 have been associated with magnesium deficiency. McColloch et al. (29) found that when the exchangeable-K/Mg ratio of soil was used to describe the magnesium content of the foliage, 83% of the variance in the leaf magnesium was related to the variance of the exchangeable-K/Mg ratio of the 18- to 30-inch soil depth.

Salmon (33) reports that the glasshouse and the horticultural crops have suffered from magnesium deficiencies and usually such deficiences have been associated with large potassium dressings. Ward and Miller (43) indicate that the magnesium deficiency associated with the excessive use of potash fertilizers is particularly noticeable in greenhouse vegetables such as tomatoes and cucumbers. Branson et al. (3) reported the occurrence of potassium-induced magnesium deficiency at several commercial greenhouses in the San Francisco Bay Area.

C. FACTORS AFFECTING MAGNESIUM DEFICIENCY

1. pH

The magnesium content of plants is affected both by the soil pH and the available potassium. Adams and Henderson (1), however, found that the effects of the two factors on the magnesium content of the plants were independent of each other. The magnesium content of plants at deficient potassium levels was greater than at adequate potassium levels for the same soil, regardless of the soil pH.

2. Concentration

According to Welte and Werner (44) magnesium deficiencies will occur only where soil magnesium is at deficiency levels and only under those circumstances will generous potash dressings have an aggravating effect. Adams and Henderson (1), however, found that the effect of potassium on magnesium content of plants was generally greater on magnesium-sufficient soils than on magnesium-deficient soils. Ward and Miller (43) were not successful in producing the symptoms of magnesium deficiency in tomatoes by the application of excess potassium. It resulted in a high potassium content in leaves but the magnesium content was not depressed.

3. Soil temperature

The data presented by Del Valle and Harmon (9) indicate an increase in the uptake of magnesium by turnips with increase in soil temperature up to a maximum at 65 to 75 F. With further increase in the temperature to 85 F there is a fall in the magnesium uptake. Lingle and Davis (27) found that the magnesium uptake in tomatoes

increased with an increase in soil temperature from 50-55 to 70-75 F and then remained relatively the same at 80-85 F. However, potassium continued to increase over the entire range of soil temperatures from 50-55 to 80-85 F. Cannel et al. (6) did not get any significant effect upon the uptake of magnesium in tomatoes over a soil temperature range of 54 to 96 F. Potassium, however, increased with the increase in temperature, the effect being curvilinear.

4. Light intensity

Winsor et al. (46) obtained a significant yield response with magnesium applications on magnesium-deficient tomato plants in only one out of four years, but, that one year coincided with a particularly sunny season. They suspect some relationship to exist between magnesium deficiency and light intensity because chlorosis has often been observed to be more severe in greenhouses on plants adjacent to the glass. No other evidence confirming or refuting this contention was found in the literature.

MATERIALS AND METHODS

A. Experiment I. Effect of K-Mg antagonism on tomato plant growth, fruit yield and uptake of major cations

I. Experimental lay out

One hundred forty four tomato plants, cv Michigan-Ohio Hybrid were grown in individual 20 cm plastic pots using perlite as a growth medium. The seeds were obtained from Stokes Seeds Limited, St. Catherines, Ontario. Three seeds were sown per pot and allowed to germinate in the perlite moistened only with distilled water. After germination the seedlings were thinned to one only per pot. Care was taken to ensure retention of seedlings of comparable vigor.

The seedlings were watered as needed with distilled water and fed weekly with nutrient solutions. The nitrate-type standard nutrient solution as used at Long Ashton (16) including the minor elements as per the recommendations of Hoagland and Arnon (17) was prepared with variations in the potassium and magnesium levels as required by the various treatments. Potassium and magnesium were applied at two and six levels, respectively. The levels for potassium were 4 meq and 12 meq per liter of nutrient solution and the levels for magnesium were 0.125, 0.25, 0.375, 0.50, 1.5 and 3.0 meq per liter. This resulted in twelve treatments. Using two plants per treatment the twelve treatments were randomized. The experiment was laid out in the greenhouse in a simple factorial design with six replications. The pH of the nutrient solutions was 5.1 ± 0.1.

2. Rating for symptom development

A point system for rating the plants was arbitrarily devised to represent the severity of symptom development. The grades used were:

No chlorosis	0
Traces	1
Mild	2
Moderate	3
Severe	4
Extreme	5

Nine weeks after the emergence of the seedlings, when the symptoms were fully developed, three persons were requested to grade the plants. They graded them on the same day but independently. To prevent bias on the part of the judges, labels depicting the treatment of each pot were replaced with code numbers. The six grades awarded per treatment per replication were averaged and the results subjected to the analysis of variance and the Duncan's miltiple-range test (35).

3. Assessment of the plant growth

Plant growth as influenced by the various treatments was assessed on the basis of dry weight production. One plant per treatment within each replication was harvested eleven weeks after the emergence of the seedlings and was separated into roots, stem and leaves. These were washed and dried in a forced-draft oven at 70 C. The dry weights were recorded and the average weight per plant calculated and subjected to statistical analysis (35). The average of six replications is recorded as the dry weight per plant for each of the

twelve treatments.

4. Analysis of the mineral content

Each dried sample was ground in a Wiley mill to pass a 60 mesh screen. The ground sample was homogenized by means of thorough mixing. A weighed quantity was ashed in a muffle furnace and the minerals extracted according to the procedure outlined by Ward and Johnston (42). The extracts were analysed for calcium, magnesium and potassium on a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer.

The spectrophotometer was set and operated as per the directions supplied with the instrument. Standard solutions with concentrations of 0.0 (blank), 0.25, 0.50, 1.0, 2.0 and 2.5 parts per million for magnesium and 0.0 (blank), 1, 2, 4, 8 and 10 parts per million for calcium and potassium were used for plotting the standard curves each time samples were analysed. The standard solutions of the above concentrations were prepared from the certified atomic absorption standard reference solutions for the respective elements supplied by the Fisher Scientific Co., Chemical Manufacturing Division, Fair Lawn, New Jersey, U.S.A.

The plant tissue extracts were diluted with known volumes of distilled water so that the concentrations of the resulting solutions fell within the concentration range of the standard solutions. From the value obtained in terms of parts per million of the element in the diluted solution, the original concentration as percentage of dry weight was calculated. The average of six replications (6 plants) is reported as the concentration of the particular element in the part of the plant under investigation.

The data were subjected to analysis of variance and Duncan's multiple-range test (35).

5. Evaluation of the fruit yield

After the harvest of one plant per treatment within each replication for the assessment of the growth and the mineral analysis, there still was left one plant per treatment replication which was allowed to mature and produce fruit. The plants were topped above the third truss and trained to a single stem. The fruit was allowed to set and was harvested as it matured. Records were maintained for the total quantity and the number of fruits harvested from each treatment.

B. Experiment II. Influence of soil temperature and potassium fertilization on the uptake of major cations by tomato plants

Four water tanks with mechanical temperature controls and each having eight holes large enough for the insertion of 25 cm pots up to the rim were installed in the greenhouse. These tanks were used for the investigation of the influence of soil temperature and potassium fertilization on the mineral uptake by tomato plants.

Thirty two plastic pots of 20 cm size were filled with perlite and moistened with distilled water. The seeds of tomato, cv Michigan-Ohio Hybrid, obtained from Stokes Seeds Ltd., St. Catherines, Ontario, were sown at the rate of three to a pot. After emergence only one seedling per pot was retained. Care was taken to ensure that the seedlings retained were of comparable size

and vigor.

After seed germination each pot was fitted into a 25 cm plastic pot having drainage holes plugged by rubber stoppers of appropriate size. The inner pot rested on the ends of those rubber stoppers thereby providing for limited drainage. The outer pot also formed a water-proof jacket for the inner pot in which the seedling was growing. The rubber stoppers prevented the escape of nutrient solution into the tank and the entrance of tank water into the treatment solution.

The temperature of water in the four tanks was set at 12.8, 18.3, 23.9 and 29.4 C respectively and maintained within a range of $\pm$ 1C. Eight plants in as many pots were raised under each of the four substrate temperatures.

The plants were watered as needed with distilled water and fed weekly with nutrient solutions. The nitrate-type standard nutrient solution as used at Long Ashton (16) including minor elements as per recommendations of Hoagland and Arnon (17) was prepared with variations in the potassium levels as required by the two potassium treatments. Half of the number of plants under each substrate temperature received potassium at the rate of 4 meq per liter of nutrient solution. The other half received it at 12 meq per liter. For each of these eight substrate temperature x potassium concentration treatments there were four plants.

Eleven weeks after emergence the plants were harvested. These were washed and dried in a forced-draft oven at 70 C.

Each dried sample was ground in a Wiley mill to pass a 60 mesh screen. The ground sample was homogenized by mixing it thoroughly. A weighed quantity of the homogenized sample was

ashed and the extract made according to the procedure given by Ward and Johnston (42)

The ash extracts were analysed for magnesium, potassium and calcium on a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer. The procedure followed was the same as described under Experiment I.

C. Experiment III. Influence of light intensity and potassium fertilization on the uptake of major cations by tomato plants

Tomato seeds of cvs Tuckqueen and Michigan-Ohio Hybrid were obtained from Stokes Seeds Limited, St. Catherines, Ontario. These seeds were sown and allowed to germinate in the greenhouse. After emergence the seedlings were transplanted into flats. Seven weeks after transplanting thirty six seedlings of each variety were planted singly in 20 cm plastic pots filled with a well blended soil mixture of 2 parts soil to 1 part each of sand an peat. Care was taken to ensure that the seedlings transplanted were of comparable size and vigor.

Plants of each variety were raised under two levels of light and two levels of soil potassium for a total of eight treatments. Each treatment was replicated three times with a total of nine plants (3 plants/replication). Within each replication the treatments were randomized.

Two greenhouse compartments were selected which had reasonably similar environments except for light. In one compartment the day light penetrated the glass directly while the other compartment was naturally shaded by adjacent tall buildings. Half of the number

of plants of each variety were grown in each of the compartments. Eight weeks after the experiment was begun all the plants were shifted into one compartment. Reduction of light was achieved by shading with two layers of cheese cloth. This enabled the plants growing under two levels of light intensity (shaded and not shaded) to get a more uniform environment with respect to temperature, humidity etc. Light intensity readings in foot candles were taken thrice daily at 9 A.M., 1 P.M., and 3 P.M. The intensity of light under low light averaged over the period of growth was 444, 862 and 587 foot candles at 9 A.M., 1 P.M. and 3 P.M. respectively. The corresponding averages under the 'high-light' intensity were 807, 2624 and 1675 foot candles respectively.

Standard soil analyses* were run on the soil mixture prior to potting the seedlings. The available potassium was reported as 10 parts per million in the soil mixture extract. All plants were fertilized similarly in respect to all essential nutrient elements except potassium. Potassium was applied as potassium sulphate and varied according to the treatment to enable maintenance of a 'low' and a 'high' level of potassium for each variety of tomatoes under each light intensity level. The plants were fertilized 5, 9 and 11 weeks after transplanting. A sample of the soil medium for analysis was taken seven weeks after transplanting. Soil samples were taken from each pot and grouped according to the treatments. These were submitted for analysis to the same laboratory referred to earlier. The potassium levels after seven weeks under the various treatments are reported in Table I.

The plants were sampled for foliar analysis 8 and 14 weeks after transplanting. The tissue samples consisted of the fifth

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* Agricultural Soil and Feed Testing Laboratory, Edmonton, Alberta.

Table 1. Potassium concentration (ppm) in soil extract* under various treatments of Experiment III, 7 weeks after transplanting

Treatment			
Variety	Potassium	Light	Available-K (ppm)
Tuckqueen	Low	Low	15
Michigan-Ohio Hybrid	Low	Low	12
Tuckqueen	Low	High	16
Michigan-Ohio Hybrid	Low	High	12
Tuckqueen	High	Low	40
Michigan-Ohio Hybrid	High	Low	34
Tuckqueen	High	High	32
Michigan-Ohio Hybrid	High	High	36

* 5 g soil extracted with 25 ml 0.025 N acetic acid (Spurway method).

leaves from the growing tips and included both rachis and the lamina (28, 41, 43).

Leaf samples from the plants receiving the same treatment were grouped together each time the sampling was done. These were washed with distilled water and dried in a forced draft oven at 70 C. The dried samples were ground in a Wiley mill, mineral extract prepared and analysis for magnesium, calcium and potassium performed as per the procedure previously outlined under Experiment I.

D. Experiment IV. Influence of magnesium deficiency on tomato yields as related to the stage of plant maturity

Seventy two plastic pots of 20 cm size were filled with perlite moistened with distilled water. Tomatoes cv Michigan-Ohio Hybrid, were seeded in these at the rate of three to a pot. The seeds were obtained from Stokes Seeds Limited, St. Catherines, Ontario. After germination only one seedling per pot was retained. Care was taken to select seedlings of comparable size and vigor.

The plants were watered as needed and fed with nutrient solutions every week. Two types of nutrient solutions were prepared as follows:

1. Normal solution: Nitrate-type standard nutrient solution as used at Long Ashton (16) with the minor elements provided according to the recommendations of Hoagland and Arnon (17).

2. Mg-deficient solutions: Same as solution 1 (normal solution) but containing no magnesium salts.

The experiment included 12 treatments replicated six times.

Within each replication the treatments were randomized. The treatments are outlined below:

Treatment No.	Type of nutrient solution fed
1.	No. 1 for first week followed by No. 2 thereafter
2.	No. 1 for first 3 weeks followed by No. 2 thereafter
3.	No. 1 for first 5 weeks followed by No. 2 thereafter
4.	No. 1 for first 7 weeks followed by No. 2 thereafter
5.	No. 1 for first 9 weeks followed by No. 2 thereafter
6.	No. 1 for full experimental period
7.	No. 2 for first week followed by No. 1 thereafter
8.	No. 2 for first 3 weeks followed by No. 1 thereafter
9.	No. 2 for first 5 weeks followed by No. 1 thereafter
10.	No. 2 for first 7 weeks followed by No. 1 thereafter
11.	No. 2 for first 9 weeks followed by No. 1 thereafter
12.	No. 2 for the full experimental period

The plants were topped above the third truss and the fruit in these trusses allowed to develop. The fruit was harvested 20 weeks after transplanting. The average of six replications is reported as yield under each treatment. The data was subjected to analysis of variance and Duncan's multiple-range test (35).

RESULTS

A. Symptoms of magnesium deficiency

1. General symptoms

The visible symptoms of magnesium deficiency were first apparent about two weeks after the emergence of the seedlings. The magnesium deficient plants showed a restricted growth (Fig. 1). Within limits an increase in the concentration of magnesium in the nutrient solution resulted in an increase in the size of the plants.

The characteristic symptom of magnesium deficiency was the development of inter-veinal chlorosis (Fig. 2). The area around the veins remained green but the leaf tissue between the veins turned yellow. Under continued magnesium deficiency the leaves turned brown (necrotic) and were shed prematurely.

The deficiency symptoms were invariably more pronounced on the older leaves than on the younger leaves. In severe cases all older leaves towards the base of the plant were shed prematurely; the newly formed leaves at the tip continued to be green whilst the leaves along the middle of the stem were pale and often showed purplish coloration.

The deficiency of magnesium severely restricted the root growth. The roots of magnesium-deficient plants were short and sparsely branched.

2. Influence of K-Mg antagonism on magnesium deficiency symptoms

The severity of the symptom development on the leaves, under each treatment, is indicated in Table 2. Under both levels of

Fig. 1. Tomato plants growing under decreasing concentrations of magnesium (left to right, 3.00, 0.375, 0.250, 0.125 and 0.00 meq/liter).

Fig. 2. A magnesium-deficient tomato plant showing inter-veinal chlorosis.

Table 2. Intensity of foliar symptoms of Mg deficiency under various concentrations of substrate magnesium and potassium.

Treatment	*Index of symptom development	
(meq Mg^{++}/liter)	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	# 4.23 f	3.94 ef
0.25	3.47 de	3.26 cd
0.375	2.61 b	2.79 bc
0.50	2.25 b	2.58 b
1.50	0.42 a	0.20 a
3.00	0.36 a	0.25 a

* Rating for chlorosis (5 = Extreme, 4 = Severe, 3 = Moderate 2 = Mild, 1 = Traces, 0 = Nil).

Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

potassium nutrition the symptoms decreased with increasing concentrations of magnesium in the nutrient solution. Virtually no symptoms developed when the magnesium concentration in the nutrient solution was maintained at 1.50 meq or higher per liter.

The analysis of variance indicated that the substrate concentrations of magnesium have a highly significant influence on the development of foliar symptoms. Neither the potassium nutrition, nor its interaction with magnesium appeared to affect symptom development. Duncan's multiple-range test showed no significant difference in the symptom expression under the two potassium levels of nutrition at any of the magnesium concentrations in the nutrient solution.

B. Influence of K-Mg antagonism on tomato plant growth and yield

1. Influence on the growth of the plants

The average dry weights of the eleven week old plants obtained from the various treatments are given in Table 3. Maximum growth, measured on the dry weight basis, was obtained under the lower level of potassium at a minimum magnesium concentration of 0.375 meq per liter of nutrient solution. Comparable growth under the higher potassium level was not obtained till the magnesium concentration was 0.50 - 1.50 meq/liter of nutrient solution.

Statistical analysis revealed a highly significant influence of magnesium nutrition on the dry weight production. The potassium nutrition and its interaction with magnesium, also affected significantly the dry weights of the plants.

Table 3. Dry weight of eleven week old tomato plants under various concentrations of substrate magnesium and potassium

Treatment ($meq\ Mg^{++}$/liter)	Dry weight per plant (g) 4 $meq\ K^{+}$/liter	12 $meq\ K^{+}$/liter
0.125	# 4.36 a	5.74 a
0.25	8.54 b	7.44 a
0.375	15.06 c	6.92 a
0.50	15.87 c	12.67 bc
1.50	16.06 c	15.20 c
3.00	16.07 c	15.50 c

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

2. Influence on the fruit yield

i. Influence on the total fruit yield

The average total fruit yield per plant is given in Table 4. The analysis of variance showed a highly statistically significant influence of both magnesium and potassium nutrition and their interaction on the fruit yield of the plants.

The fruit production increased with increase in the substrate magnesium concentration irrespective of the potassium level. The maximum yield, under the low level of potassium is obtained at a minimum magnesium concentration of 0.50 meq/liter. Comparable yield under the high level of potassium is obtained at a minimum level of 1.50 meq magnesium per liter.

At substrate magnesium levels of 1.50 meq per liter and at concentrations lower than that, the fruit yeild showed a trend towards being less under the higher level of potassium than under the lower level. However, these differences were statistically significant only at substrate magnesium levels of 0.375 and 0.50 meq/liter.

ii. Influence on the average weight of individual fruits

The average weight of the harvested fruits under the various treatments is given in Table 5. Statistical analysis shows that there is a highly significant influence of magnesium nutrition on the average weight of the individual fruits.

The average weight of the individual fruits is significantly less at the lowest magnesium concentration in the nutrient solution as compared to that at the highest magnesium concentration. Under

Table 4. Tomato fruit yield under various concentrations of substrate magnesium and potassium.

Treatment	Average fruit yield per plant (g)	
(meq Mg^{++}/liter)	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 254.8 a	241.8 a
0.25	338.2 bc	316.5 b
0.375	394.5 d	341.3 bc
0.50	574.0 e	372.8 cd
1.50	573.2 e	541.5 e
3.00	567.5 e	578.8 e

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

Table 5. Average weight of individual tomato fruits under various concentrations of substrate magnesium and potassium.

Treatment (meq Mg^{++}/liter)	Average weight of individual fruit (g)	
	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 38.60 a	48.20 b
0.250	48.48 b	63.32 cd
0.375	54.48 bc	56.17 bc
0.50	69.25 d	55.01 bc
1.50	59.42 c	56.62 bc
3.00	61.64 cd	58.94 c

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

the low concentrations of magnesium (0.125 and 0.25 meq/liter) the average weight of the fruits from the plants grown under 12 meq potassium per liter was more than those from the plants growing under 4 meq potassium per liter.

iii. Influence on the total number of tomato plants

The average number of fruits per plant is given in Table 6. The statistical analysis showed that there was a highly significant influence of the magnesium and potassium nutrition on the number of fruits produced per plant. The interaction of these two nutrients also had a significant influence on the number of fruits.

The increasing concentrations of magnesium in the nutrient solution increased the number of fruits per plant till the maximum was reached at 1.5 meq magnesium per liter under both levels of potassium. Under the low concentrations of magnesium (0.125 and 0.25 meq/liter) the number of fruits produced at the lower potassium level was significantly higher than that produced at the higher potassium concentration.

C. Influence of K-Mg antagonism on chemical content

1. Magnesium

i. Magnesium content of the indicator tissue

The magnesium content of the indicator tissue for each of the treatments is given in Table 7. The indicator tissue consisted of the fifth leaf from the growing point and this was usually the newest fully developed leaf.

The statistical analysis indicated a significant increase in the magnesium content of the sample tissue with increases in

Table 6. Number of tomato fruits produced per plant under various concentrations of substrate magnesium and potassium.

Treatment (meq Mg^{++}/liter)	Average number of fruits per plant 4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 6.67 c	5.17 ab
0.25	7.00 cd	5.00 a
0.375	7.33 cd	6.33 bc
0.50	8.33 de	7.00 cd
1.50	9.67 ef	10.17 f
3.00	9.33 ef	9.83 f

* Within or between columns figures not followed by the same letter are significantly different from each other ($P = 0.05$) according to Duncan's multiple-range test.

Table 7. Magnesium content of *indicator tissue in tomato plants under various concentrations of substrate magnesium and potassium.

Treatment	Magnesium content of the indicator tissue (percent dry weight)	
(meq Mg^{++}/liter)	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	# 0.20 a	0.26 b
0.25	0.28 b	0.29 bc
0.375	0.33 cd	0.37 d
0.50	0.35 d	0.38 d
1.50	0.47 e	0.51 ef
3.00	0.57 fg	0.60 g

* Fifth leaf from the growing tip.

Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

substrate magnesum under both the levels of potassium.

The minimal substrate levels which gave the greatest fruit yield (Table 4) were 0.50 and 1.50 meq magnesium per liter under low and high potassium, respectively. The magnesium content of the indicator tissue in these treatments was 0.35% and 0.51% (Table 7), respectively. These values are significantly different from each other.

ii. Magnesium as percentage of dry weight

The magnesium content of the tomato plants as affected by magnesium nutrition under the two substrate levels of potassium is given in Table 8. Irrespective of the kind of tissue involved and the level of potassium fertilization, the magnesium content significantly increased with increases in substrate magnesium.

The magnesium content of the stem tended to be higher under the low potassium than under the high potassium at all the levels of substrate magnesium (statistically significant at substrate magnesium levels above 0.50 meq/liter). In the leaves, however, there was essentially the same content at each substrate level of magnesium regardless of the substrate potassium level.

The magnesium content as percentage of total dry weight of the aerial part of the plant at the lower levels of substrate magnesium appears to be less under low potassium than under high potassium but the differences are not statistically significant. At the higher levels of substrate magnesium there is a reversal of this trend (Fig. 3).

Table 8. Magnesium content of tomato plants under various concentrations of substrate magnesium and potassium

Treatment	Magnesium content (percent of dry weight)					
	Stems		Leaves		Whole Plant*	
(meq Mg^{++}/liter)	4 meq K^+/liter	12 meq K^+/liter	4 meq K^+/liter	12 meq K^+/liter	4 meq K^+/liter	12 meq K^+/liter
0.125	#0.02 ab	0.01 a	0.05 a	0.06 ab	0.04 a	0.05 ab
0.25	0.03 abc	0.02 ab	0.06 ab	0.08 b	0.05 ab	0.06 bc
0.375	0.06 cd	0.05 bc	0.09 bc	0.13 e	0.08 cd	0.10 de
0.50	0.09 e	0.08 de	0.15 d	0.16 d	0.13 e	0.13 e
1.50	0.29 h	0.17 f	0.37 e	0.43 e	0.34 f	0.33 e
3.00	0.50 i	0.24 g	0.69 f	0.71 f	0.62 h	0.53 g

* Includes stem plus leaves

\# Figures not followed by the same letter, within each group (i.e., stems, leaves, whole plants) are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

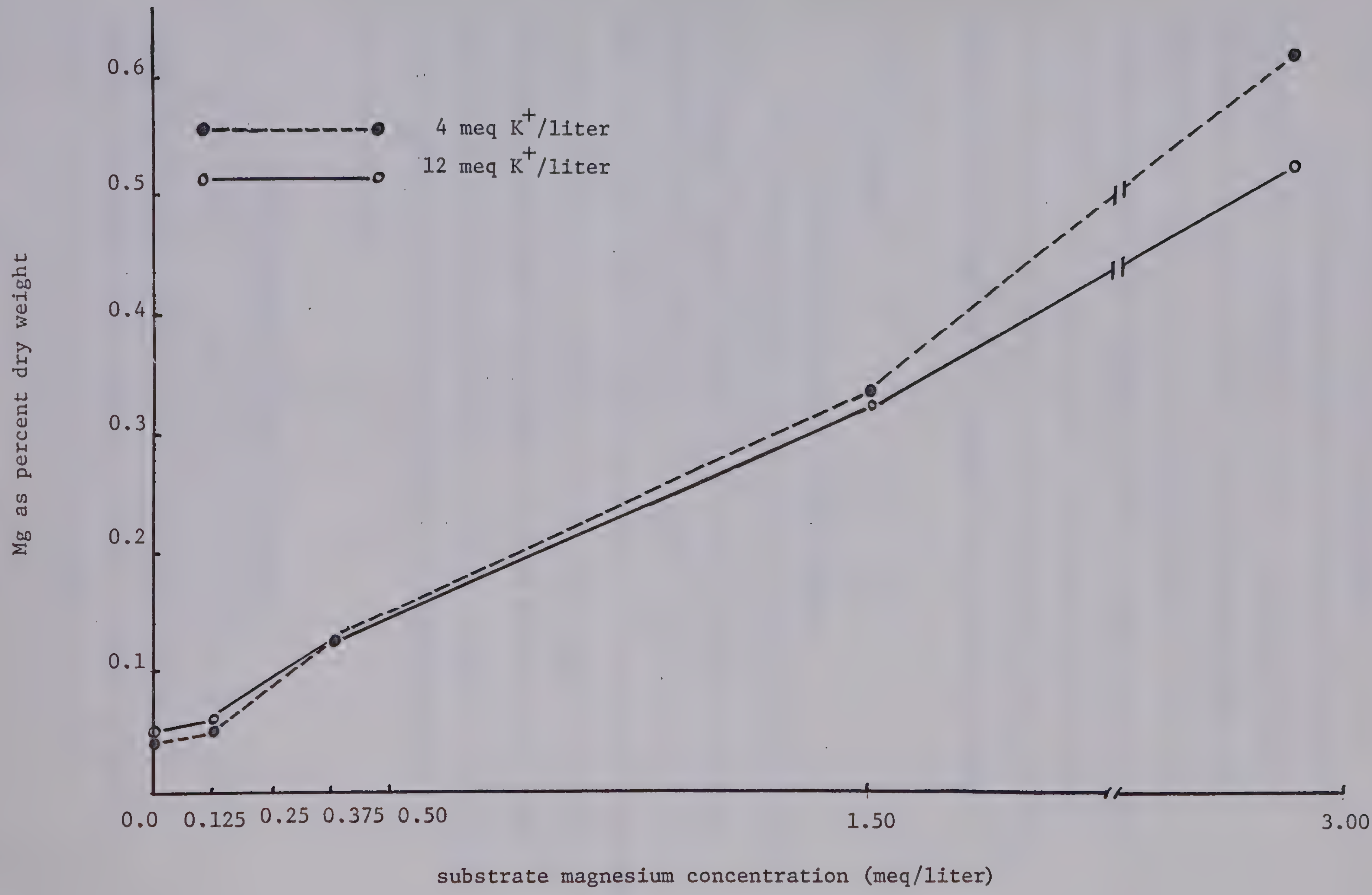

Fig. 3 Mg uptake in tomato plants as influenced by K-Mg antagonism

iii. Total magnesium uptake by the plants

The total magnesium uptake by the plants as affected by substrate levels of magnesium and potassium is given in Table 9. The analysis of variance showed a highly significant effect of magnesium nutrition on the total magnesium uptake. Under both levels of potassium, the magnesium content of the plants increased with the increase of the magnesium concentration in the nutrient solution. Neither the effect of potassium nor its interaction with magnesium has any significant influence on the magnesium uptake.

2. Potassium

i. Potassium as percentage of dry weight

The average concentration of potassium (expressed as percent of dry weight) in aerial portion of the plant is given in Table 10. An increase in the concentration of potassium in the substrate very significantly increased the potassium content of the plants, irrespective of the substrate level of magnesium. Under both levels of potassium there was a trend towards decreasing potassium content in the plant with increase in substrate magnesium. However, significant decreases occurred only under the low potassium and low concentrations of substrate magnesium.

ii. Total potassium uptake by the plants

The influence of magnesium and the potassium nutrition on the total potassium content in the tomato plants is indicated in Table 11. The statistical analysis indicated a highly significant effect of both potassium and magnesium nutrition on the total

Table 9. Total magnesium in tomato plants under various concentrations of substrate magnesium and potassium

Treatment ($meq\ Mg^{++}/liter$)	Average total magnesium per plant (mg)	
	4 meq K^+/liter	12 meq K^+/liter
0.125	* 1.61 a	2.81 a
0.25	3.95 a	3.94 a
0.375	11.00 ab	6.68 ab
0.50	18.92 b	14.87 ab
1.50	48.41 c	47.79 c
3.00	89.08 d	78.10 d

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

Table 10. Potassium content of tomato plants under various concentrations of substrate magnesium and potassium

Treatment ($meq\ Mg^{++}$/liter)	Potassium in the aerial portion of the plant (percent of dry weight)	
	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 6.05 c	7.06 d
0.25	4.90 b	7.45 d
0.375	3.84 a	7.17 d
0.50	3.76 a	7.18 d
1.50	3.76 a	6.98 d
3.00	3.75 a	6.85 d

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

Table 11. Total potassium in tomato plants under various concentrations of substrate magnesium and potassium

Treatment ($meq\ Mg^{++}$/liter)	Average total potassium per plant (g)	
	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 0.251 a	0.477 ab
0.25	0.39 ab	0.51 b
0.375	0.537 b	0.464 ab
0.50	0.557 b	0.851 c
1.50	0.527 b	0.969 c
3.00	0.527 b	1.001 c

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

potassium uptake. The interaction of the two nutrients was also significant.

At most of the substrate magnesium levels the potassium content of the plants was higher under higher substrate potassium than under lower substrate potassium. This difference was significant only under substrate magnesium levels of 0.50 meq and higher per liter.

Within limits, increments of magnesium in the substrate increased the total potassium uptake under either of the substrate potassium levels. This limit was reached at substrate mangesium concentrations of 0.25 meq/liter and 0.50 meq/liter under the low and the high substrate potassium, respectively.

3. Calcium

i. Calcium as percentage of dry weight

The calcium content as percentage of the total dry weight of the aerial portion of the plants is given in Table 12. The statistical analysis indicated a highly significant effect of magnesium nutrition, whereas, the potassium nutrition did not have any significant influence. The interaction of magnesium and potassium was also significant.

ii. Total calcium uptake by the plants

The average total calcium uptake by the plants is indicated in Table 13. The analysis of variance revealed a highly significant effect of magnesium nutrition. The influence of potassium nutrition and its interaction with magnesium is also significant. Duncan's

Table 12. Calcium content of tomato plants under various concentrations of substrate magnesium and potassium

Treatment	Calcium in the aerial portion of the plant (percent of dry weight)	
(meq Mg^{++}/liter)	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 1.59 abcd	1.90 d
0.25	1.71 bcd	1.44 abc
0.375	1.74 cd	1.39 abc
0.50	1.56 abcd	1.60 abcd
1.50	1.43 abc	1.38 ab
3.00	1.36 ab	1.32 a

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

Table 13. Total calcium in tomato plants under various concentrations of substrate magnesium and potassium

Treatment ($meq\ Mg^{++}$/liter)	Average total calcium per plant (g)	
	4 meq K^{+}/liter	12 meq K^{+}/liter
0.125	* 0.06 a	0.10 a
0.25	0.14 ab	0.10 a
0.375	0.24 c	0.09 a
0.50	0.24 c	0.19 bc
1.50	0.20 bc	0.20 bc
3.00	0.21 bc	0.20 bc

* Within or between columns figures not followed by the same letter are significantly different from each other (P = 0.05) according to Duncan's multiple-range test.

multiple-range test shows no significant increase in calcium content of plants under low potassium at substrate magnesium concentrations of 0.375 meq or more per liter. This limit under the high substrate potassium is reached at substrate magnesium concentrations of 0.50 meq/liter.

D. Mineral content of tomato plants under various soil temperatures and potassium fertilization levels

Table 14 gives the mineral content as the percent of total dry weight of the plants grown under two levels of potassium fertilization and four substrate temperatures.

Under the low level of potassium (4 meq/liter) the magnesium content of the plants increased with increase in substrate temperature. This increase was appreciable up to 23.9 C. At the next higher temperature (29.4 C) the increase was very little. Under the high substrate potassium (12 meq/liter) the increase in the magnesium content with the increase in the temperature was comparatively very moderate up to 23.9 C. At the highest temperature (29.4) there was a decrease in the magnesium content of the plants.

The comparative magnesium contents under the two potassium levels and the four substrate temperatures is also shown in Fig. 4. Comparing the levels of magnesium in the plants under the two levels of substrate potassium one notes that the difference widened with the increase in temperature.

The potasssium content of the plants under the low level of potassium (4 meq/liter) showed an increasing trend up to substrate temperature of 23.9 C. Further increase in temperature to 29.4

Table 14. Mineral content of tomato plants under various soil temperature and potassium substrate levels

Substrate temperatures (C)	Mineral content of the plants (Percent of dry weight)					
	Magnesium		Potassium		Calcium	
	4 meq K^+/liter	12 meq K^+/liter	4 meq K^+/liter	12 meq K^+/liter	4 meq K^+/liter	12 meq K^+/liter
12.8	*0.39	0.44	1.87	7.30	1.53	1.33
18.3	0.50	0.47	2.91	6.75	1.39	1.38
23.9	0.70	0.56	3.21	7.63	1.41	1.12
29.4	0.75	0.45	3.05	7.30	1.24	0.88

* Each figure is an average from four plants.

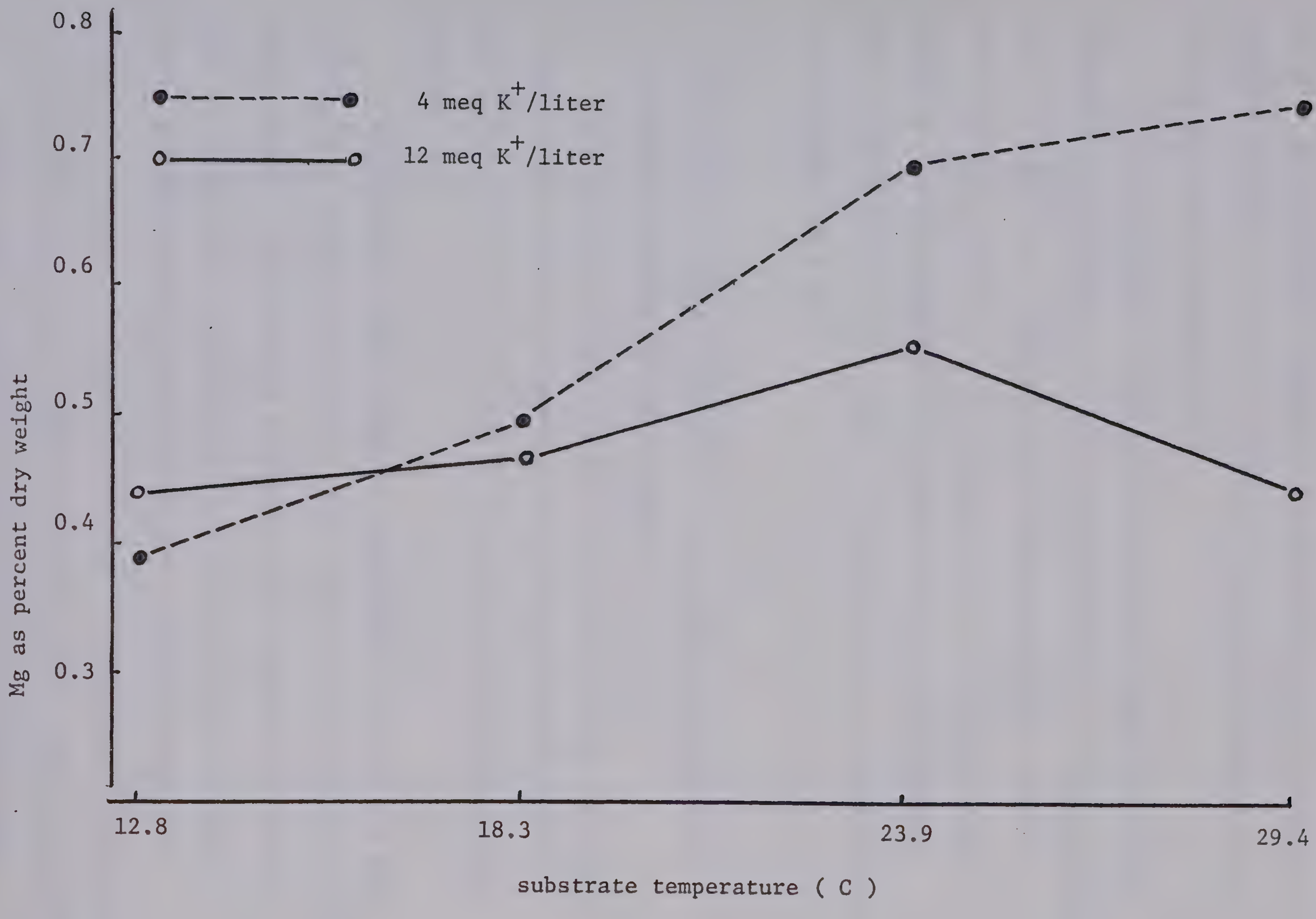

Fig. 4 Mg content as percent dry weight of tomato plants grown under four substrate temperatures and two levels of potassium

resulted in a depression in potassium uptake. Under the high substrate level of potassium the potassium content of the plants at various temperatures did not show any consistent trends and appear not to be much different from each other.

Calcium showed a trend of moderately decreasing levels in the plants with increase in substrate temperature at the low potassium level (4 meq/liter). This trend was comparatively more marked under the high potassium level (12 meq/liter). The decreasing trends of calcium content of the plants (as percent dry weight) with increase in substrate temperature under the two potassium levels is illustrated in Fig. 5.

E. Influence of light intensity and potassium fertilization on the mineral content of tomato plants

The magnesium, potassium and the calcium contens expressed as percent dry matter for tomato plants growing under different light intensities and two levels of substrate potassium are given in Table 15.

The magnesium level showed a decreasing trend with the age of the plants irrespective of the light levels or the level of potassium fertilization. The magnesium percentage also appears to be lower under the high light intensity (at least in the first sampling), but the differences are neigher marked nor consistent making it difficult to draw any definite conclusions. The potassium fertilization did not appear to have any appreciable effect on the magnesium uptake.

In most cases the plants growing under the higher levels

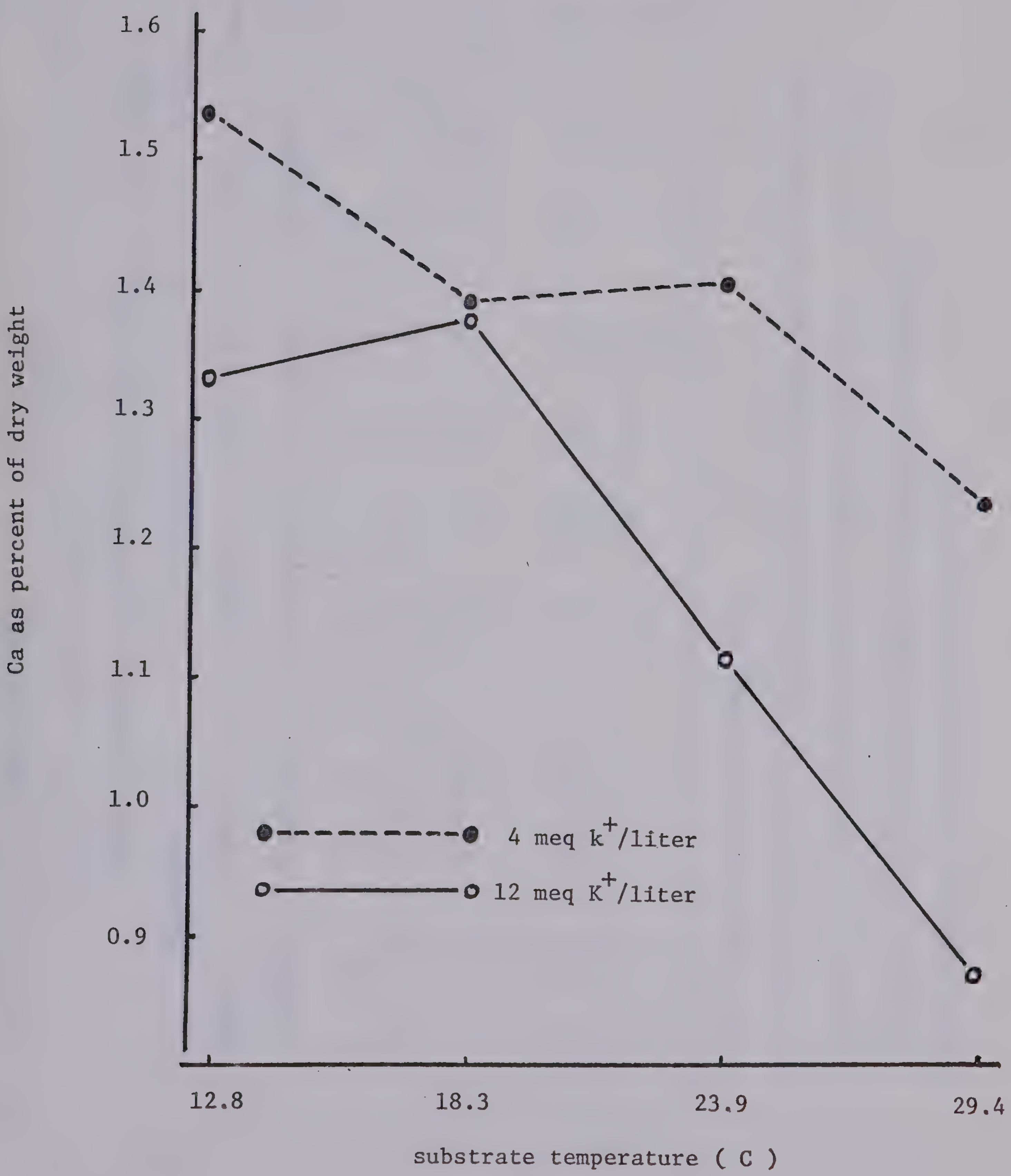

Fig. 5 Ca content as percent dry weight of tomato plants grown under four substrate temperatures and two levels of potassium.

Table 15. Influence of light intensity and potassium fertilization on the mineral compostion of the *indicator tissue of tomato plants

		Mineral compostion of indicator tissue (percent of dry weight)											
		Magnesium				Potassium				Calcium			
		Sample I (8 weeks)		Sample II (14 weeks)		Sample I (8 weeks)		Sample II (14 weeks)		Sample I (8 weeks)		Sample II (14 weeks)	
		L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
#V_1	K_1	+0.86	0.59	0.28	0.38	2.14	1.97	1.58	1.39	2.25	2.22	1.18	2.67
	K_2	0.74	0.49	0.40	0.49	2.67	2.11	2.52	1.52	2.00	2.16	1.55	2.46
#V_2	K_1	0.85	0.55	0.34	0.52	2.19	1.83	2.64	1.63	2.40	1.77	0.98	1.88
	K_2	0.70	0.50	0.43	0.48	2.36	2.98	2.45	2.38	1.77	1.86	1.37	2.07

* Fifth leaf from the growing point.

V_1 and V_2 are varieties Tuckqueen and Ohio-Michigan Hybrid, respectively.

K_1 and K_2 are low and high levels of substrate potassium, respectively.

L_1 and L_2 are low and high light intensities, respectively.

+ Each figure is an average from nine plants.

of potassium showed a higher percentage of potassium in the indicator tissue. The intensity of light also appears to affect the potassium uptake. The indicator tissue sampled both after eight weeks and fourteen weeks showed a trend of having higher potassium content under less light. The potassium content was fairly uniform over the age of the plants.

There was no marked effect on the calcium content of the plants except for the fact that the tissue samples taken fourteen weeks after transplanting had relatively less calcium content in the plants grown under less intensity of light.

F. Influence of magnesium deficiency developed at different stages of growth in tomato plants

The influence of the replacement of the normal nutrient solution by magnesium-free nutrient solution at different stages of growth, on fruit yield, is given in Table 16. The analysis of variance revealed a highly significant treatment effect. Through the application of Duncan's multiple-range test it is found that development of a magnesium deficient environment after nine weeks of normal growth did not significantly affect the fruit yield.

With regard to fruit yield, the influence of feeding tomato plants started as magnesium deficient, with a normal nutrient solution is given in Table 17. The statistical analysis shows no significant increase if the normal solution was applied earlier than three weeks after emergence.

Table 16. Fruit yield as influenced by inducing magnesium deficiency at different stages of growth in tomato plants.

Treatment	Average fruit yield per plant (g)
Normal nutrient solution for entire experimental period	* 498.3 d
Normal nutrient solution for 9 weeks #	500.2 d
Normal nutrient solution for 7 weeks	380.1 c
Normal nutrient solution for 5 weeks	365.1 c
Normal nutrient solution for 3 weeks	359.8 c
Normal nutrient solution for 1 week	254.4 b
Normal nutrient solution for 0 weeks+	44.9 a

* Figures not followed by the same letter are significantly different from each other ($P = 0.05$) according to Duncan's multiple-range test.

\# Followed by Mg-deficient solution.

\+ Mg-deficient solution for entire experimental period.

Table 17. Tomato fruit yield as influenced by correction of magnesium deficiency at different stages of growth.

Treatment	Average fruit yield per plant (g)
Mg-free nutrient solution for entire experimental period	* 44.9 a
Mg-free nutrient solution for 9 weeks #	93.0 a
Mg-free nutrient solution for 7 weeks	120.2 a
Mg-free nutrient solution for 5 weeks	260.0 b
Mg-free nutrient solution for 3 weeks	430.6 c
Mg-free nutrient solution for 1 week	479.8 c
Normal nutrient solution for entire experimental period	498.3 c

* Figures not followed by the same letter are significantly different from each other ($P = 0.05$) according to Duncan's multiple-range test.

Followed by normal solution.

DISCUSSION

The potassium-magnesium antagonism is an established phenomenon. This phenomenon, however, becomes important for practical purposes only if potassium reduces the uptake of magnesium to such an extent that it results in a reduction of the crop yeilds. Holmes (19) has reported that high rates of potassium tended to decrease the yield of potatoes as compared to a more normal rate and at least in one of his experiments this reduction of yield was attributed to potash-induced magnesium deficiency. In the present experiments plants under low substrate potassium (4 meq/liter) gave the maximum dry weight (Table 3) when magnesium in the nutrient solution was at least 0.375 meq/liter. Comparable quantity of dry weight was obtained under the high substrate potassium (12 meq/liter) only when the substrate magnesium was at least 0.50 - 1.50 meq/liter. The maximum fruit yield (Table 4) was obtained with minimum magnesium substrate levels of 0.50 and 1.50 meq/liter under the low and the high substrate potassium respectively.

The average number of tomato fruits produced per plant is significantly affected by magnesium and potassium nutrition (Table 6). Substrate potassium does not appear to affect the number of fruits produced per plant when the substrate magnesium is high (1.5 meq/liter or higher). However, under the low magnesium levels (0.125 - 0.250 meq/liter) less fruits are produced when potassium is high (12 meq/liter) than when it is low (4 meq/liter). The number of fruits produced under the low substrate potassium and 0.125 meq magnesium per liter are statistically comparable to the number

produced under the high substrate potassium when substrate magnesium is increased to 0.375 meq per liter.

Thus increased potassium in the nutrient solution induces magnesium deficiency of a magnitude sufficient to reduce plant growth, fruit yield (weight) and the average number of fruits produced per plant. The antagonistic effect of potassium on magnesium is greatest when substrate magnesium is relatively low. This is in agreement with an observation of Welte and Werner (44) that magnesium deficiency will occur only when soil-Mg is at a deficiency level and only under those circumstances is a generous potash dressing likey to have an aggravating effect.

The minimum substrate levels of magnesium which were necessary for maximum plant growth (dry weight of plants) were not the same as those necessary for maximum fruit yield (comparison of Tables 3 and 4). The soil nutrient levels necessary for maximum plant growth and fruit yield are not necessarily the same. Cummings (8) reported yield responses from the application of potassium on peaches even when there was no response on the tree growth.

The results of the study on the effect of K-Mg antagonism on the average weight of the individual fruits (Table 5) indicates a significant effect of magnesium nutrition. Under magnesium deficiency conditions the average weight of individual fruits is less. Woodbridge (47) reported that apples are smaller in size from magnesium deficient trees than from non-deficient trees. Reduction in the weight of the individual tomato fruits is more under low substrate potassium than under high substrate potassium.

Potassium appears to compensate for low magnesium, to some extent, in helping to maintain the weight of the individual tomato fruits.

The study on symptom expression revealed that irrespective of the level of substrate potassium no visible symptoms (chlorosis) were present when the magnesium concentration in the nutrient solution was 1.5 meq or more per liter. As a general rule growth may be restricted due to limiting supply of a mineral even when no visible symptoms are present. Such a deficiency is termed 'Hidden Hunger' (37). It appears that magnesium deficiency does not conform to this principle. In this study the visible symptoms (mild to moderate chlorosis) were present even when the growth was not restricted. Howlett (21) has pointed out that tomato plant growth is often, if not usually, not appreciably reduced due to magnesium deficiency until it becomes severe. This perhaps explains for no response to applications of magnesium on plants showing magnesium deficiency symptoms as reported by some workers (19,20). In such plants the supply of magnesium is restricted to the extent that visual symptoms are produced but it is not low enough to reduce the plant growth or the fruit yield.

The mineral analysis of plant tissue (Table 8) indicates that the concentration of magnesium in the stem tends to be higher under lower potassium than under high substrate potassium levels at all levels of substrate magnesium (24). These differences are statistically significant at substrate magnesium concentrations of 1.5 meq or higher per liter. The situation in the leaves, however, is quite different. They have essentially the same magnesium content at each substrate level of magnesium regardless of the substrate potassium level. This could be interpreted as a stress on magnesium

in the leaf tissue when substrate potassium is high. The magnesium tends to accumulate in the leaves at the expense of the stems.

The magnesium contents as percentage of the total dry weight of the aerial part of the plant at substrate magnesium levels up to 1.5 meq/liter are comparable under the two substrate potassium levels (Table 8). In spite of this the plants show less growth, at least at magnesium concentrations of 0.25 and 0.375 meq/liter (Table 3), under the high substrate potassium. Similarly lower fruit yield is obtained under the higher substrate potassium level at magnesium concentrations of 0.375 and 0.50 meq/liter (Table 4). Under increased substrate potassium there is an apparent necessity for more magnesium. The problem, therefore, is not that the uptake of magnesium is hindered but that magnesium apparently becomes unavailable within the plant. This unvavailability of magnesium probably occurs in the leaves since there is an accumulation of it therein.

At the highest substrate concentration of magnesium the uptake of magnesium is significantly reduced by high substrate potassium. There appears to be, therefore, a definite hinderance in magnesium uptake only at the higher levels of both magnesium and potassium in the substrate.

The level of magnesium in the leaf remains constant at each of the substrate magnesium levels regardless of the stress imposed on uptake by the potassium substrate levels. Ward and Miller (43) tried to develop potassium-induced magnesium deficiency in tomatoes by using 3 meq magnesium and 12 meq potassium per liter of nutrient solution. No symptoms were produced even after 73 days. Results

indicated a high potassium content in the leaves but an undepressed magnesium level. The authors suggest that the amounts of potassium were not large enough to prevent absorption of magnesium. The present investigations, however, indicate that there could have been an undetected depression of magnesium in their plants. Apparently only the leaves were analysed and as already noted (Table 8) leaves will not show any depression. Under similar nutritional conditions to those used by Ward and Miller a decrease of over 50% in stem magnesium and a decrease of about 15% magnesium for the entire aerial portion of the plant were observed. These decreases are statistically significant.

Magnesium also exerts an antagonistic effect on the potassium uptake of tomato plants (Table 10). However, significant decrease in potassium uptake occurs only under low potassium and the lower concentrations of magnesium in the nutrient solution. It can be inferred from this that magnesium hinders the uptake of potassium but this antagonistic effect is significant only under low substrate concentrations of both potassium and magnesium (24). This is opposite to the conditions under which potassium exerts an antagonistic effect on magnesium, i.e., higher concentrations of the two elements.

The total uptake of magnesium (Table 9) is significantly affected by substrate magnesium. The total uptake of potassium (Table 11) is significantly affected by magnesium and potassium nutrition. The total uptake of either of these elements, however, appears basically to be a function of plant growth and the level of fertilization of the respective elements.

The calcium content expressed as percentage of dry weight appears to increase with increase in substrate magnesium up to a

concentration of 0.375 meq/liter (Table II) under low substrate potassium. However, this is merely a trend and not statistically significant. A further increase in substrate magnesium shows a depression in the calcium content. At a substrate magnesium level of 3 meq/liter the magnesium-calcium antagonism appears to be operative resulting in significantly less calcium in the aerial parts of the plant relative to that present at 0.375 meq magnesium per liter. Under the high substrate potassium (12 meq/liter) the trend of magnesium-calcium antagonism becomes evident at a much lower concentration of magnesium in the nutrient solution (0.25 meq/liter). Thus high magnesium and potassium act together in antagonising the uptake of calcium by tomato plants.

The total uptake of calcium (Table 13) under either of the substrate potassium levels is essentially proportional to the plant size. Nevertheless, under low substrate potassium (4 meq/liter) and at magnesium concentrations of 1.5 meq/liter and higher there is a decreasing trend in total calcium uptake suggestive of a depressing effect of high substrate magnesium levels. However, the depressing effect not being statistically significant cannot be taken as a very conclusive result especially in the absence of a similar effect under high substrate potassium.

Plant tissue analysis as a means for diagnosis for the nutritional needs of agri cultural crops have become a well recognised practice. Many investigators have published sets of values for optimal nutritional levels in different crops. Ward and Miller (43) found incipient magnesium deficiency in tomato plants cv Michigan-Ohio Hybrid to be associated with a magnesium level of 0.30% of dry

weight of sample leaves but recommended a level of 0.45% for healthy normal growth of greenhouse tomatoes. In the present investigations the magnesium levels associated with maximum fruit yield (Table 4) are 0.35% and 0.51% (Table 6) for plants under the low and high levels of potassium, respectively. The former is in close proximity to Ward and Miller's value of 0.30% but the latter is significantly higher. Foliar analysis, therefore, cannot be considered a simple tool for diagnosing the nutritional needs, at least, in cases where ion interactions are involved. No definite values can be assigned to any element. One can interpret the foliar analysis data for formulating a fertilizer program only after careful consideration of all nutrient elements both in the tissue and the substrate. This is in agreement with the observations of Froshey (14) that the failure to consider such factors as crop load, weather, and the relationship between elements can seriously limit the value of leaf analysis for diagnostic purpose.

The experiments on the effects of substrate temperature and potassium fertilization, and light intensity and potassium fertilization indicate a possible influence of these factors on the incidence of magnesium deficiency. A high rate of potassium fertilization and high soil temperatures (Table 14) can act together in aggravating the problem of magnesium deficiency (25). This possibly explains why the reports of magnesium deficiency in greenhouses, in spite of normal substrate magnesium levels, are more frequent on warm crops such as tomatoes, cucumbers and chrysanthemums than on cool crops. This could also be one reason why tomatoes frequently do better in ground beds than on raised benches - the former having

better buffering capacity against high day temperatures. Under high light intensity there was a trend towards less magnesium uptake than under the low light conditions, but, in view of the limited scope of the experiment no firm conclusions could be drawn. Continuation of investigations on these lines would perhaps be worth while.

Foliar analysis of vegetable crops provide a unique problem not encountered with fruit crops. Vegetable crops are mostly one season crops and before leaf analysis can be performed the crop has to be grown for some time. This leads to a possibility of a detection of deficiency of an element at too late a stage for any redress. The experiment investigating the effect of magnesium deficiency at different growth stages of the crop on fruit yield, however, indicates that magnesium deficiency can lead to no substancial loss of tomato fruit yield if it is corrected within three weeks of the emergence of the seedlings (Table 17). Tomato seeds perhaps have enough magnesium in them to withstand at least this short period of time without any reduction in yield. That tomato seedlings can withstand this short period of magnesium deficiency is not an unusual phenomenon. Johnston and Walker (23) found the growth and vigor of strawberry plants growing for sixteen weeks in magnesium deficient cultures to be equivalent to that of plants receiving complete nutrients.

The occurrence of magnesium deficiency nine weeks after emergence of seedlings did not affect the tomato yields. In the event of magnesium deficiency occuring in a greenhouse tomato crop any time after nine weeks of emergence of the seedlings, the application of a magnesium fertilizer can be postponed without any significant loss in fruit yield. However, before the next crop is planted the deficiency should be redressed.

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